Robot control and assembly policy learning for deformable industrial parts based on dynamic simulation

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Problem:

Manufacturing and performance bottlenecks are often caused by the difficulty of assembling complex industrial parts. Modern industrial robotics are capable of executing such intricate tasks with high precision and speed compared to traditional methods. However, the focus of robotic manipulation has predominantly been on manipulating rigid objects. Many assembly tasks still currently performed by humans involve manipulation of deformable objects, which presents a considerable amount of challenges in robot solutions.

Force applied to a rigid object simply results in an external wrench that moves the object, which can be simulated using a simple dynamic model for a given object, manipulator and environment. Force applied to a deformable object both moves the object and changes its shape. The combination of deformation and external wrench depends on the precise material composition of the object, which means the material properties such as elasticity and plasticity become a critical part of the system dynamics, leading to complex dynamic models.

This PhD will be a part of the Green H2 and MeOH in DK (GREMEOH) project, which focuses on green Power-to-X (PtX) solutions. GREMEOH aims to reduce the cost of green hydrogen and methanol to fossil parity in order to aid Europs transition to carbon neutrality by 2050. The current bottlenecks of PtX solutions are the ability to assemble electrolyser stacks at high precision and speed, which consist of many deformable parts.

GREEN HYDROGEN SYSTEMS

Objectives:

The main hypothesis is to show that through assembly policy learning with a conjuction of an accurate state model of the deformable object, an efficient and reliable robot control can be achieved. Furthermore, the control policy can enhance the robot solutions that can be deployd in classical industrial manufacturing currently performed by humans.

The project aims to establish a robotics simulation framework for modeling intricate assembly tasks involving deformable components, such as assembly of PtX electrolyser stack assembly. In addition, methods will be developed for estimating the system dynamics and material properties of components within simulations, addressing the gap between the digital simulation and physical environment in a Digital-Twin manner.

Model predictive control (MPC) will be used to generate optimal robot motion trajectories and predict both the robot motion and the interaction forces between the robot and the environment.

This project aims to address the following questions:

- How can learning-based approaches be used to create efficient offline motion trajectory planning strategies for manipulation of deformable objects?

- In what ways can predictive control be used for online adjustment and optimization of these trajectories?

- How can a simplified model of deformable objects be estimated for control purposes?

Methodology:

The environment for an assembly task will be simulated along with the relevant deformable and rigid industrial parts and a robot arm. The simulation will be created in NVIDIA Isaac Sim, a robotics simulation application with high physics fidelity that includes synthetic data-generation tools for photorealistic virtual environments.

This simulation will be used to test the proposed control and policy learning schemes on the simulated robot arm, and to generate enough relevant data from simulated vision and force-torque sensors in order to train reinforcement learning- and MPC models for assembly policy learning.
The physical robot arm will also be available, along with some of the deformable parts that need to be assembled in the electrolyser stack. Once the assembly policy learning models have been trained in the simulation, they will be tested on the physical robot and deformable parts. This will both provide new data for training the models, and data on the behaviour of the real deformable parts that can be used to improve upon the dynamic models of the parts in the simulation.